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Handover Aspects for a Low Earth Orbit (LEO) CDMA Land Mobile Satellite (LMS) System.

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Abstract

This paper addresses the problem of handoff in a land mobile satellite (LMS) system between adjacent satellites in a low earth orbit (LEO) constellation. In particular, emphasis is placed on the application of soft handoff in a Direct Sequence Code Division Multiple Access (DS-CDMA) LMS system. Soft handoff is explained in terms of terrestrial macroscopic diversity, in which signals transmitted via several independent fading paths are combined to enhance the link quality. This concept is then reconsidered in the context of a LEO LMS system. A two-state Markov channel model is used to simulate the effects of shadowing on the communications path from the mobile to each satellite during handoff. The results of the channel simulation form a platform for discussion regarding soft handoff, highlighting the potential merits of the scheme when applied in a LEO LMS environment.

Introduction:

The market penetration of terrestrial mobile cellular systems in Europe is ultimately limited both economically and geographically. As a result, activities within ETSI addressing UMTS (Universal Mobile Telecommunications System), concerning the design of third generation land mobile communications systems in Europe, are now looking at the possibility of a satellite-based radio interface to complement the service areas offered by terrestrial networking.

A preliminary study into the integration of LMS and terrestrial communications systems at the University of Bristol has suggested that the focus of a future LEO CDMA LMS system design will be towards that of low bit rate services (up to 9.6Kbps) enhancing a subset of the UMTS objectives [1] e.g. voice via hand held portable units.

By definition, providing continuous coverage over a specified region requires frequent handover activations between adjacent satellites in the LEO constellation ($\approx$ 10-15 min. intervals) [2]. Sectorized satellite antennas mapping cells (or sectors) onto the earths surface are key components in improving the link budget (and hence reducing mobile transmit power) and also the management of each satellite's EIRP. In contrast to terrestrial cellular systems, the cells are fixed relative to the satellite's orbit but they move rapidly across the earths surface. As a result, handover activations need to be performed at an even greater frequency (e.g. one per minute for the Iridium system [3]) between contiguous cells within a single satellite footprint.

Current research into third generation mobile terrestrial systems in Europe, more specifically the RACE CODIT [4] and LINK CDMA [5] projects, are focusing on interference limited multiple access techniques, such as DS-CDMA (Direct Sequence - Code Division Multiple Access). This spread spectrum technique transmits the signal in a bandwidth in excess of the minimum necessary to send the information. The band spread is accomplished by means of a high bit rate code which is independent of the transmitted data, and a synchronized reception with the code at the receiver is used for despreading and subsequent data recovery. DS-CDMA can support a form of signal diversity at the mobile, where signals from more than one transmitter can be combined to support a system feature known as soft handoff [6].

The requirement for a CDMA soft handoff protocol to operate in a LEO LMS environment is clear: the user must experience as little disruption as possible during a call handoff either from sector to sector within a single satellite's footprint or from satellite to satellite.

LEO LMS System Description:

In order to study the problems of satellite handover, it is instructive to define a simplified LMS network topology. The results of any subsequent protocol simulation can be used to form a platform for further investigation and help establish the basic limitations that the handoff process places on the LMS system.

In Figure 1, a communication link between a Mobile station and an earth gateway is considered. The space segment in any communications network demands a high capital investment, and in the case of LEO LMS systems, satellites will need to be replaced after several years of operation. It is therefore logical to assume a very simple space hub design, which is limited to the function of frequency translation between the uplink and downlink. At the mobile the designer has to optimize transmit power, battery life and the size of the hand portable unit. To this end a large proportion of the network functions (e.g. routing and protocol management) are concentrated at earth gateways, which in principal will also provide the necessary interface to contemporary terrestrial systems. In addition LMS system Gateways are separated by large geographical distances and this property implies that each Gateway requires a degree of autonomy when considering the design of system operating protocols. Each earth gateway is updated with essential network information through store-and-forward techniques over the space hub.

LMS Shadowed Channel Model:

A main cause of signal level variation in the LMS environment is shadowing, in which obstructions in the radio communications path cause reduced local mean signal levels in areas tens or hundreds of metres in extent. This phenomena is particularly important in a LEO LMS system where the handover period between adjacent satellites in the constellation can last for several minutes.

Considering the slow signal variations due to shadowing, the LMS channel can be represented by a two-state channel model formulated by [7]. Areas of high received signal power correspond to line-of-sight operation and the channel state is described as *good*. Conversely, shadowed areas with low received signal powers are represented by a *bad* channel state. The switching

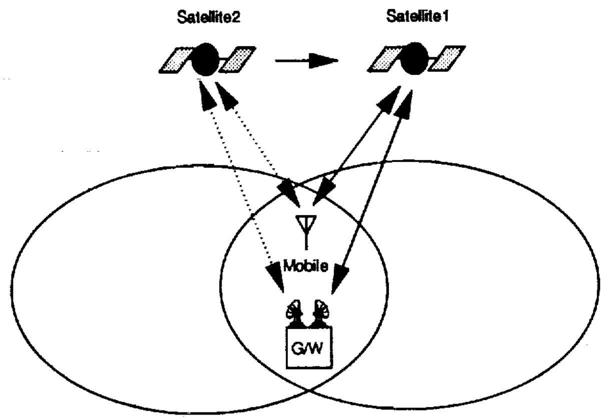

Figure 1: *Handoff between two adjacent satellites.*

process between the shadowed and unshadowed areas in which the mobile is operating can be approximated by a Markov model, see Figure 2. The durations of the good and bad channel states, t_g and t_b, are exponentially distributed.

The associated means of the channel state durations depend on the vehicle speed $v[m/s]$ and are given by,

$$\bar{t}_b = \frac{1}{P_{bg}} = \frac{D_b}{v} \tag{1}$$

and

$$\bar{t}_g = \frac{1}{P_{gb}} = \frac{D_g}{v} \tag{2}$$

where D_b and D_g are simply the average dimensions of the obstructed and unobstructed regions respectively in metres. P_{gb} and P_{bg} are the state transition probabilities and have units of $[1/s]$.

The timeshare of shadowing A is related to the durations D_b and D_g. According to [7], it is defined as

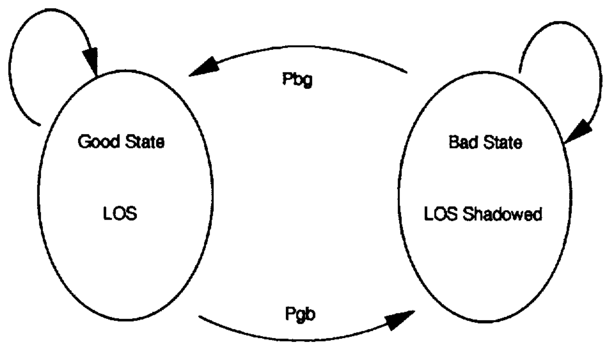

Figure 2: Two-state Markov model.

$$A = \frac{D_b}{D_g + D_b} \qquad (3)$$

For the present study and to provide an example for discussion, mean signal levels under LOS operation are governed by a linear path loss model or link equation given by,

$$\frac{C}{N_0} = EIRP_T + [\frac{G}{T}]_R - Lp - 10\log k \qquad (4)$$

$\frac{C}{N_0}$: The ratio of the signal power to noise power spectral density after being received and amplified (dB-Hz).

$EIRP$: The effective isotropic radiated power of the transmitter (dBW).

$[\frac{G}{T}]_R$: Figure of merit of receiver (dB).

L_p: Free-space path loss (dB).

k: Boltzmann's constant expressed in decibels (-228.6 dBW-K-Hz).

Equation (4) can be applied either to the forward (satellite to mobile) or reverse (mobile to satellite) direction, as well the corresponding anchor links between the satellite and earth gateway station.

Similarly, the short-term signal mean r_0, when the LOS path between the mobile and satellite is shadowed, can be approximated by a log-normal distribution.

$$f_{\log}(r_0) = \frac{10}{\sqrt{2\pi}\sigma \ln 10}\frac{1}{r_0}\exp[-\frac{(10\log r_0 - \mu)^2}{2\sigma^2}] \qquad (5)$$

where σ^2 is the variance and μ is the mean (in dB) of $10\log r_0$.

Macroscopic Diversity:

Macroscopic diversity in terrestrial systems exploits signals received at several base stations from the same mobile transmitter in order to limit the effects of signal variations due to shadowing [8]. The signals received at each base station are used by the system to select the best communications link thus enhancing the quality of service perceived by the user. This concept can also be applied in the reverse direction with the mobile combining signal paths and these could originate from one or more base stations. For example, consider the scenario depicted in Figure 1. Macroscopic diversity therefore optimizes the overall performance of a communications link with respect to quality (for DS-CDMA systems this reduces the required signal to noise ratio to support a required error rate) and signal to co-channel interference ratio. This factor becomes very significant in interference limited systems such as CDMA.

The use of macroscopic diversity dates from the 1920's, but more recently has been considered for wireless terrestrial applications such as UMTS. More specifically, interference-limited access techniques, such as DS-CDMA can utilise both base station macroscopic and mobile path diversity to provide a system feature known as 'soft handoff'. This handoff technique is by no means confined to the realms of terrestrial communications [9]. LEO LMS systems possess similar characteristics to terrestrial mobile systems. In order to provide continuous coverage over a particular region, frequent handover activations between adjacent satellites in the LEO constellation are required. In contrast to terrestrial cellular systems, the cells, defined by each satellites antenna footprint, move through the user. See Figure 3.

In a soft handoff LMS environment, as the mobile approaches the edge of one satellite's coverage region and enters that of another, a link is established via a second satellite between the mobile and communicating Gateway (routing the call to a local PSTN). The call from the mobile is now being routed via two, or possibly more, satellites. The receivers at either end of the link can have two options available, depending on their design complexity.

1. The receivers can identify the best signals from the visible satellite and combine them. This process continues until the mobile is firmly within the antenna footprint of one particular satellite.

2. If combining is not an option, all the signal options can be continuously monitored simultaneously and after a period of evaluation the best link can be selected.

Soft handoff offers an improvement over hard handoff in a LEO LMS system by being a 'make before break' rather than a 'break before make' system. The degradation experienced in terrestrial systems in the latter case is exacerbated in LMS systems due to the longer propagation time delays ($\approx$ 14ms round trip, limiting the amount of handshaking between the mobile and Earth Gateway) and longer processing delays in acquiring signals with significant Doppler shift (up to 40kHz). By careful design of the soft handoff protocol and its signal thresholds, the 'Ping-Pong' effect (constant handing back and forth between satellite channels) common in hard-handoff terrestrial systems, can be avoided.

Model Results and Discussion:

To gain an insight into the effects of shadowing during handoff a very simple scenario describing mobile handover between two adjacent satellites, separated by 45° and at an orbital height of $1000km$, in the same plane of a polar constellation was considered. The mobile was placed at some midpoint on the earth's surface, between the two orbiting satellites. This positioning implies that both satellites are visible and that the mobile is within the overlap region of the satellite 3dB antenna footprints to validate the linear path loss model.

As an example, the set of parameters listed in Table 1 were used to simulate the LMS channel model outlined. The parameters for the two state Markov model are derived from the empirical results given by

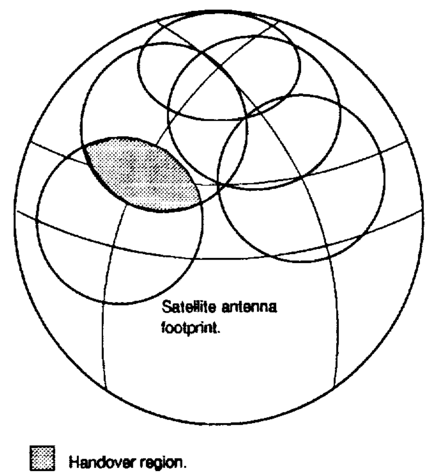

Figure 3: *A LEO polar constellation.*

[7] for a mobile to satellite elevation angle of 18° operating in a city environment. The linear path loss model is a function of the distance between the mobile and satellite and the model parameters ensure a carrier-to-noise density ratio, C/N_0, >42 dB-Hz when the mobile is in a good channel state. This minimum requirement is sufficient to provide a BER < 0.01 at 4.8kbps for QPSK modulation [10].

Figure 4 shows a 50 second time frame during the handoff period where satellite-2 is succeeding satellite-1. The two signal paths from the mobile to each satellite are shadowed, for example, by buildings. The mean Line of Sight (LOS) component is approximately constant but the additional effect of shadowing produces a variation in the signal mean by several dB. The two thresholds, T_START and T_DROP, have been arbitrarily chosen to indicate where handoff signaling in the network would start to initiate or terminate a satellite-path, as the mobile passes from one satellite footprint to another. Several potential problem areas can be identified in the use of such a window when the mobile is operating in the simulated shadowing environment.

The period of handoff in this scenario lasts for several minutes and could certainly span the duration of a subscriber call. The thresholds T_START and T_DROP are frequently crossed and in a hard handoff system, whose protocol adheres to this set of predefined signal thresholds, handoff would be initiated repeatedly. The subsequent increase in the level of signalling within the network would reduce the satellite's battery lifetime. In addition the signaling between the mobile and gateway is limited by relatively long time delays. Under such severe operating conditions a threshold transition may exceed the timer limit of the system which could lead to a premature call termination of the mobile concerned. Clearly this situation is undesirable.

As mentioned previously, multiple access techniques such as DS-CDMA are able to support a feature known as soft handoff. The reliability of the diversity combining technique used is dependent on the amount of de-correlation between the fading statistics of each individual diversity branch, in this case the signals received from the mobile at the gateway via the two separate satellite paths. The slow fading (due to shadowing) on each satellite path illustrated by Figure 4 has a cross correlation factor of 0.0429. The low correlation factor implies that the probability that both signal paths will be in a deep fade simultaneously is also very low.

Several systems exist which capitalize on the uncorrelated fading statistics of several signal paths. Selection diversity is probably the simplest system of all where the signal with the best baseband signal-to-noise ratio is connected to the output. With respect to the simulated shadowing environment described, both signal paths would remain active during handoff. Although this type of mobile receiver would provide an improved RMS signal strength, multipath fading would still occur. However, in order to overcome short term fading effects a hybrid scheme using selection diversity and an equal gain or maximal ratio combiner could be used; the benefits of these techniques may be less significant as multipath in a LMS system is very weak when compared with mobile operation in a terrestrial urban environment. The improvement in the overall signal quality has been demonstrated for a terrestrial system by [11].

In a soft handoff system the mobile is combining signals from different satellite paths by implementing the techniques discussed. As a result both the mobile and satellite need to transmit less power to maintain the same signal strength as for a single satellite path during the handoff period. The reduction in transmitted power from the satellites and users in handoff reduces the noise within the system, and so could potentially increase the overall capacity for an interference limited system such as DS-CDMA.

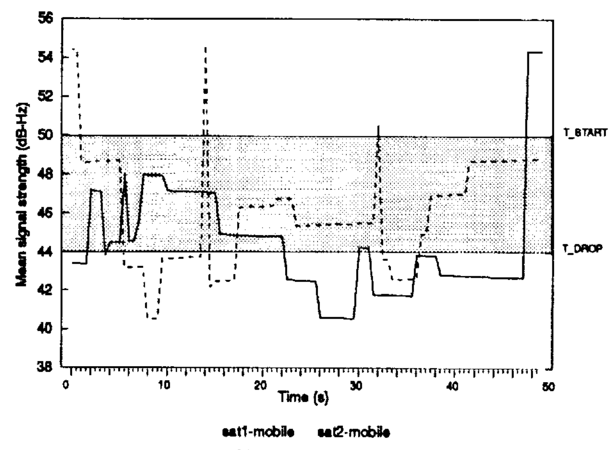

Figure 4: Short-term mean signal variation due to shadowing

PARAMETER	VALUE
EIRP/carrier	5.0 dBW
$[\frac{G}{T}]_R$	-13.0 dB-K
D_b	32.0 m
D_g	8.0 m
v	40 Km/h
A	0.80
μ	-11.8 dB
σ	4.0 dB

Table 1: Channel model parameters

Conclusions.

The simulation results presented have been used to illustrate some of the considerations necessary in order to assess handoff mechanisms in LEO LMS networks. In particular reference has been made to the soft handover concept which can have considerable benefits in interference limited systems such as DS-CDMA. Further, in LEO satellite systems any technique of reducing the satellite transponder transmit power will prolong the on-board battery-life. With regard to the design of the handoff protocol, careful consideration needs to be given as to the size of the handoff region and the timeout periods so as to prevent redundant signaling within the network. These parameters ultimately affect signal quality and network performance.

The future aims of the project are to devise a soft handoff protocol and evaluate its performance in various handover scenarios under a diverse range of signaling conditions.

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